LARP Accelerator Systems
Accelerator Physics Task 1.4.1.5

LHC Electron Lenses

Vladimir Shiltsev

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“LHC electron lens” Task Sheet

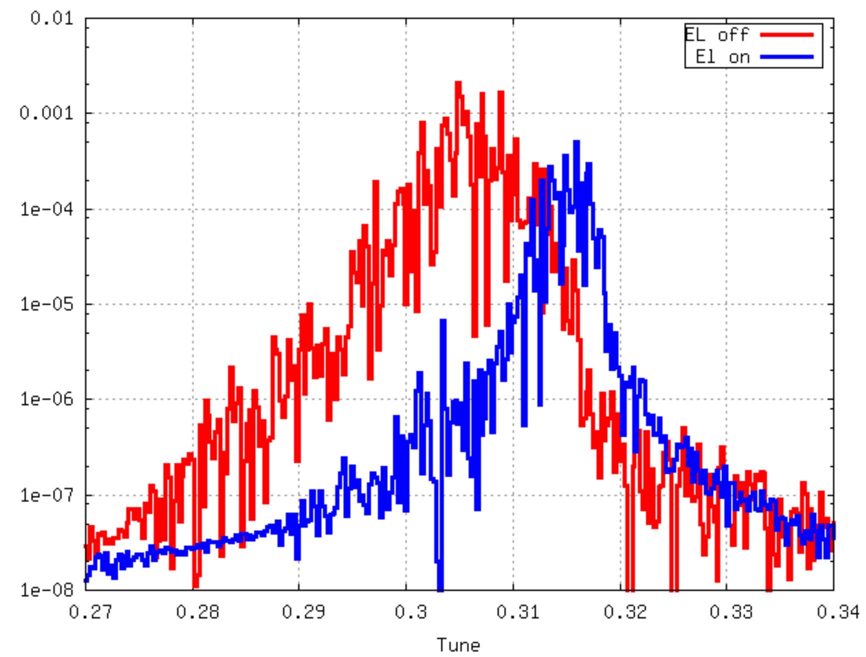
- **Statement of work for FY08:** ”..This task comprises three separate units: Numerical studies on compensation with an electron lens in the LHC, design considerations for the LHC EL, and relevant experiments in the Tevatron with TELs”
- **FY08 Deliverables:**
  - Report on numerical studies of head-on BBC in the LHC
  - Report on general layout of the LEL
  - Report on beam-beam compensation studies in Tevatron
- We asked 250k$, got 165k$

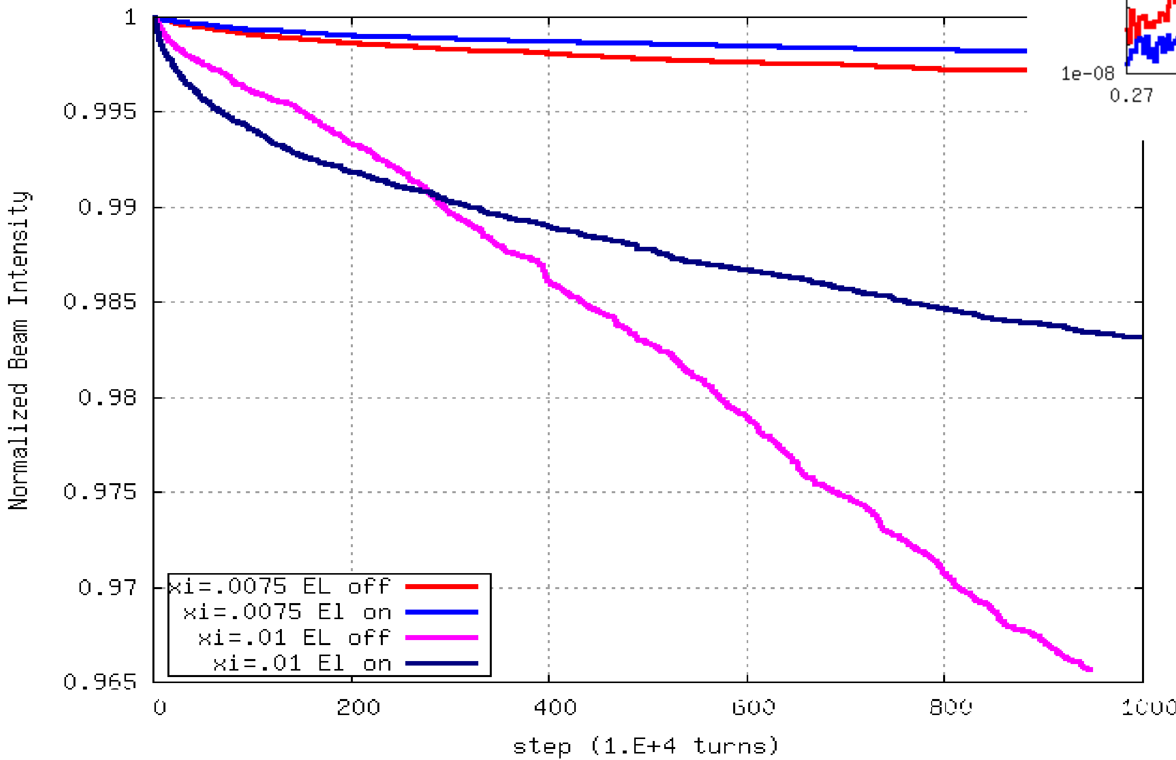
1.4.1.5 Budget

				FY Expenses + Mtl Commit. thru Mar. 31, 2008				
			Total	BNL	FNAL	LBNL	SLAC	Total
			11,918					
			954					
			12,039	1,367	1,748	2,362	677	6,154
			1,075					
			10,964	1,367	1,748	2,362	677	6,154
1.4	31.1.4	**Accelerator Physics**	700.0	31	97	94	8	231
1.4.1	31.1.4.1	Studies						
1.4.1.1	31.1.4.1.1	Electron Cloud	235.0	*2.6*	*0.0*	*74.7*	*0.0*	77
1.4.1.2	31.1.4.1.2	Beam-Beam Simulation	200.0	*0.0*	*69.5*	*19.8*	*4.2*	93
1.4.1.3	31.1.4.1.3	Wire Beam-Beam Comp.	50.0	*17.7*	*0.0*	*0.0*	*0.0*	18
1.4.1.4	31.1.4.1.4	New initiative studies	25.0	*0.0*	*0.0*	*0.0*	*0.0*	0
1.4.1.5	31.1.4.1.5	Electrons Lens	165.0	*10.4*	*27.5*	*0.0*	*4.2*	42
1.4.1.6	31.1.4.1.6	Crab Cavities	25.0	*0.0*	*0.0*	*0.0*	*0.0*	0

LHC e-Lens Simul's (A.Valishev)

- Simulation with LIFETRAC – weak-strong macroparticle code. 1E4 particles X 1E7 turns
- 6D maps and beams separations from MADX. 1st and 2nd order chromaticity, diffusion
- 1 Gaussian electron lens ~102m from IP1 with e-beam size matched to proton beam, acting as head-on tune spread





- At ξ=0.0075 (doubled beam intensity) non-luminous losses are reduced by ½
- At ξ=0.01 (triple beam intensity) life time is improved by a factor of 4!

Status of RHIC e-Lens Studies (Y.Luo)

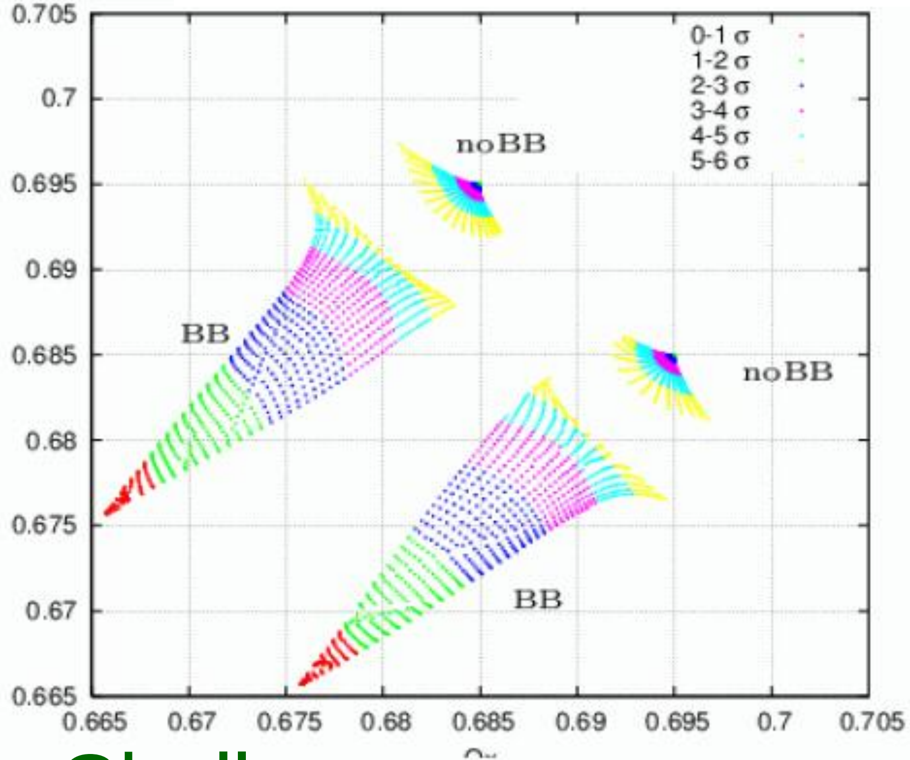
1. Study of stability of single particle motion in presence of head-on beam-beam compensation shows that head-on beam-beam compensation effectively reduces beam-beam tune shift and tune spread. Head-on beam-beam compensation stabilizes particles below 3\sigmas while destabilize particles beyond 4\sigmas.

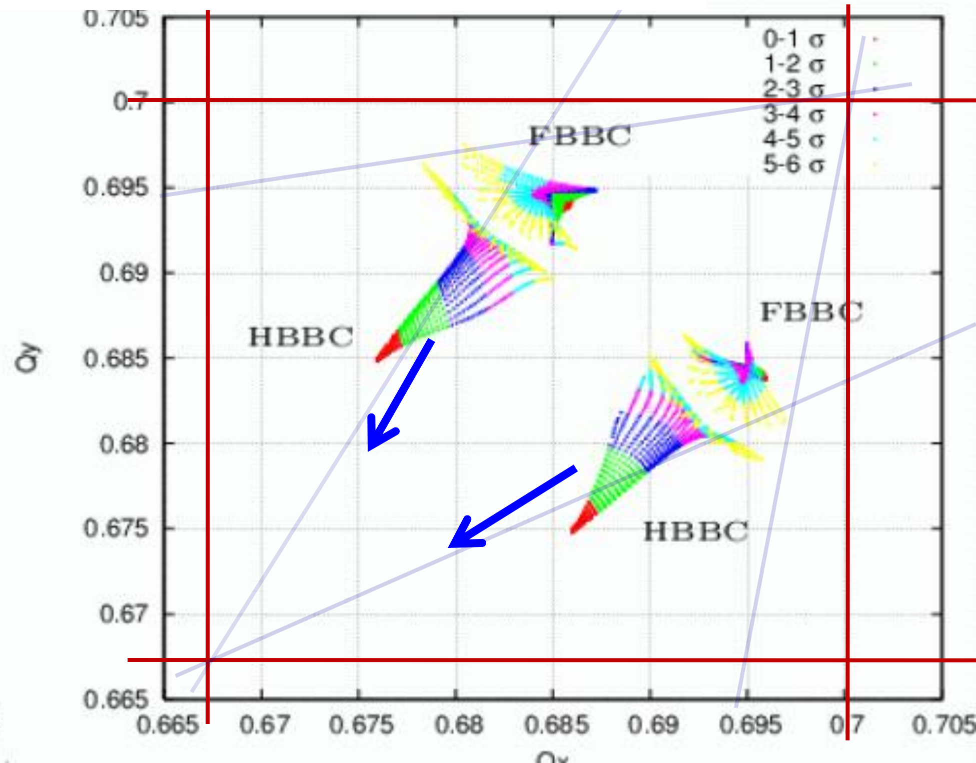
2. Preliminary multi-particle trackings show that full head-on beam-beam compensation gives much higher beam decay than that without compensation. While half head-on beam-beam compensation gives comparable beam decay as that without compensation. Emittance growth calculation is still not convincing at this moment. Numerical and analytical calculations of emittance growth are the highlight of our current study.

3. E-lens system design is progressing smoothly. E-lens system layout, electron gun, electron collector are finished, while magnetic modeling of electron transport and electron beam diagnosis are under way.

RHIC e-Lens Simulations

Y. Luo, N. Abreu, W. Fischer, G. Robert-Demolaize

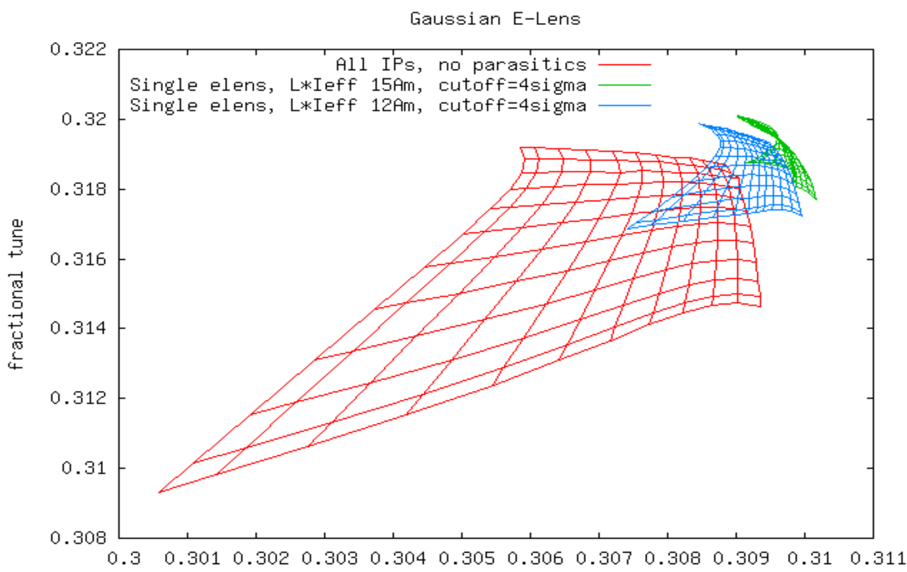


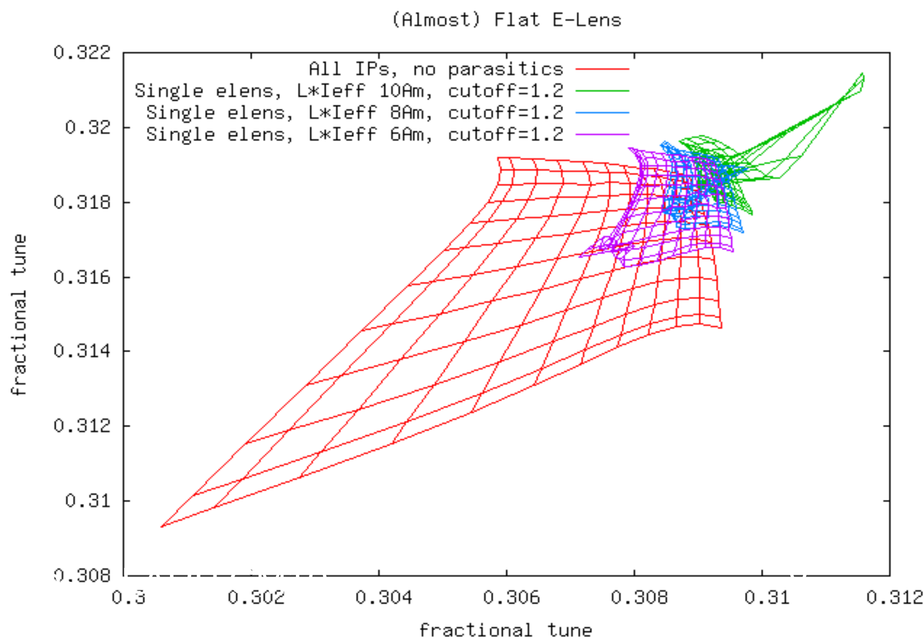


- Challenges:
  - #1 explain RHIC observed beam-beam lifetime
  - #2 optimal partial compensation+optimal Qx,y

e-Lens Simul Status SLAC (A.Kabel)

- **'Plibb' tracking code** now handles official LHC lattice, agrees to 1e-7 w/MADX optics
- Needed to add elens, new magnet types, separate rings logic, parsing, scripting, new special cases for map calculation
- Elens is drift-kick, can be cut-off gaussian, flat-top, softened flat-top
- Case considered
  - LHC, 7TeV, IP 1,2,5,8 + 4 nearest LR parasitics each, weak-strong
  - N=1.05e11 and up
  - Single elens @ -103m (beta crossing, sigm ~ 1mm), gaussian w/varying cutoff
- **tracking results:** very unsubtle test case: 1.05e11 -> 1.75e11
- Substantial losses on some 1000 turns
- Mitigated by e-lens Ieff ~ 10Am
- Quantitative results forthcoming





LAUC: LHC e-lenses

larp-doc-xxxx (2008)

Construction Project: LHC Electron Lens

V.Shiltsev, V.Kamerdziev(FNAL), W.Fischer, Y.Luo (BNL)

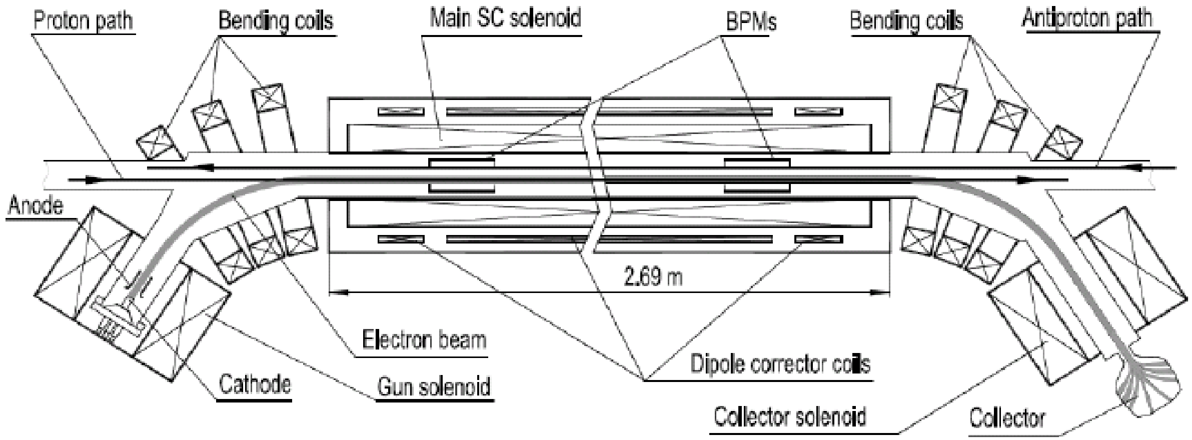


Figure 1: Electron lens configuration for compensation of beam-beam effects.

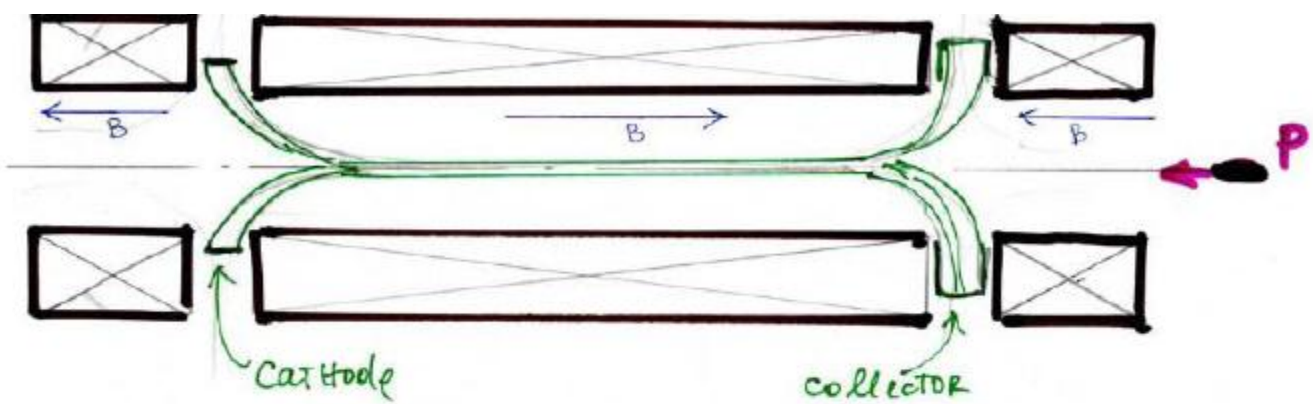


Figure 2: Electron lens configuration for collimation

LHC e-lens parameters

	Head-on BBComp	Long-range BBC	collimation
Maximum current	2.4A	10 A	10-50 A
Cathode radius/width	5 mm	7.5 mm	25 mm/ 6 mm
Magnetic Field on Cathode	2-3 kG	1-2 kG	1-2 kG
Current density on cathode	j_e=1-5 A/mm^2	j_e=1-5 A/mm^2	j_e=1-5 A/mm^2
Beta-functions @ e-IR location	$\beta_x = \beta_y$ =2300 m	$\beta_x = \beta_y$ =2300 m	$\beta_x = \beta_y$ =2300 m (altern
Beam radius @e-IR	Gaussian 1.1mm rms	Flat-top d=4mm	Hollow 4.4mm/1.1mm
Main solenoid filed	B_m=6.4T if B_{cath}=2kG	B_m=1.6Tif B_{cath}=4kG	B_m=3.2T if B_{cath}=1kG
Electron beam energy	7-10 kV	15-20 kV	10-20 kV
Regime of operation	DC	f_r=439kHz, τ=375ns	~3 kHz *sin*-modulation
Electron beam length	3m	8m	2(4)m
Magnetic fields in collector	3kG→0kG	3kG→0kG	1kG→0kG
Beam power in collector	P_{coll}=10-20 kW	P_{coll}=30-60 kW	P_{coll}=20-50 kW

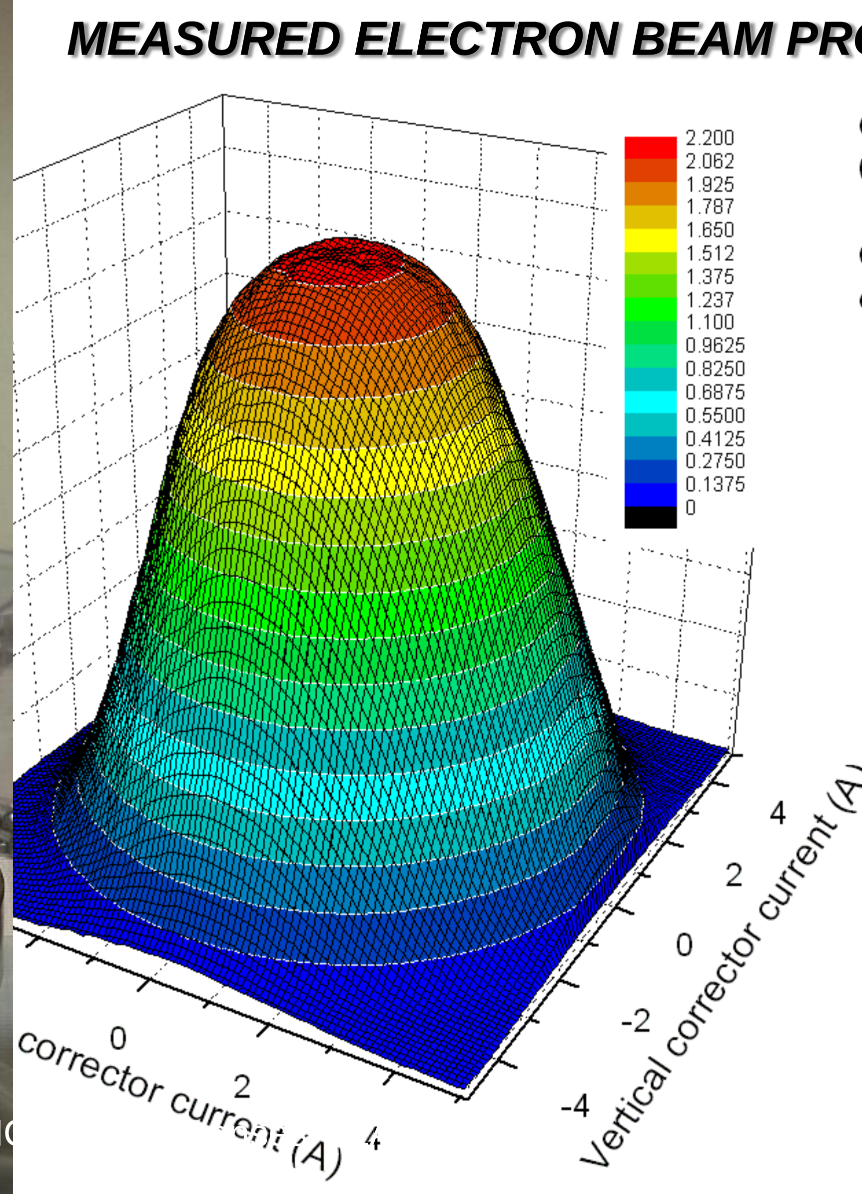
LHC e-lens cost estimates

a) 4 lenses for Head-On BBC: 11,180k$=5,980k$ (M&S)+5,200k$ (SWF)

b) 3 lenses for long-range BBC: 13,660k$=8,460k$ (M&S)+5,200k$ (SWF)

c) 3 Hollow Beam collimators: 11,470k$=6,270k$ (M&S)+5,200k$ (SWF)

Gaussian Gun (V.Kamerdzhiev)



Gaussian electron
0.4" cathode

Current density distribution

U_{cath} = -5kV
U_{ce} = -5kV
U_{anode} = -5.4kV, Gn
B_{gun} = 1.5kG
B_{main} = 2kG
B_{col} = 1.5kG
F = 200Hz
PW = 4μs

Experiments and studies

- Beam-beam compensation studies in Tevatron
  1. Electron beam size effect on proton lifetime improvement
     1. Tevatron has not ran steadily and reliably till now, waiting
  2. Quantify Improvement vs e-current *R(J_e)*
  3. Induce and detect pbar tunespread reduction or proton tunespread broadening
     - No diagnostics now - working on DTM (V.K.) in meantime
- Gaussian Gun has been built (~15k$)
  - Can probably be installed later in FY08
  - Lower in priority than #1 and gridded gun test in Tev
  - Tev next shutdown in Spring 2009
  - If gridded gun no good for operation → take one TEL out?

Summary

1. e-Lens task is on budget now, FNAL reporting system hiccups fixed
2. Experimental activities status:
   - gaussian gun fabricated and ~tested (to be cont'd and finished in FY08)
   - Tev beam studies possible but not scheduled yet
   - Hollow beam gun to be designed by EPAC
   - planning for RHIC-lens is pending the simulations progress
   - moving one of TELs to RHIC in 2009 – to be discussed
3. Simulations status:
   - LIFTRAC progress, LHC lifetime simulated - shows significant improvement by TEL
   - Simulations at SLAC – very early, but shows significant lifetime improvement by TEL, too
   - Simulations at BNL – concentrated on RHIC, see effect on emm-growth, need more work
4. Next steps - to discuss today:
   - install Gaussian-gun in Tevatron and see tunespread reduction/increase - ?
   - boost simulations for LHC at BNL, SLAC and FNAL - bring results to the level good for comparison - with a lot of investigation and post-work anticipated;
   - compare RHIC beam-beam observations (lifetime, emm growth?) with simulations;
   - should RHIC e-lens be a part of future strategy to make LHC lenses - ?

Back up slides

Numerical Simulations

- General Approach:
  - show that beam-beam effects turn "bad" above certain intensity N_p/bunch
  - either introduce wires or turn off log-range BB and see how much further increase possible
  - Turn-on e-lenses and see improvement
- Indications of "bad" in simulations
  - Dynamic aperture not observable
  - Beam lifetime measurable
  - Emittance growth measurable
  - Coherent stability measurable

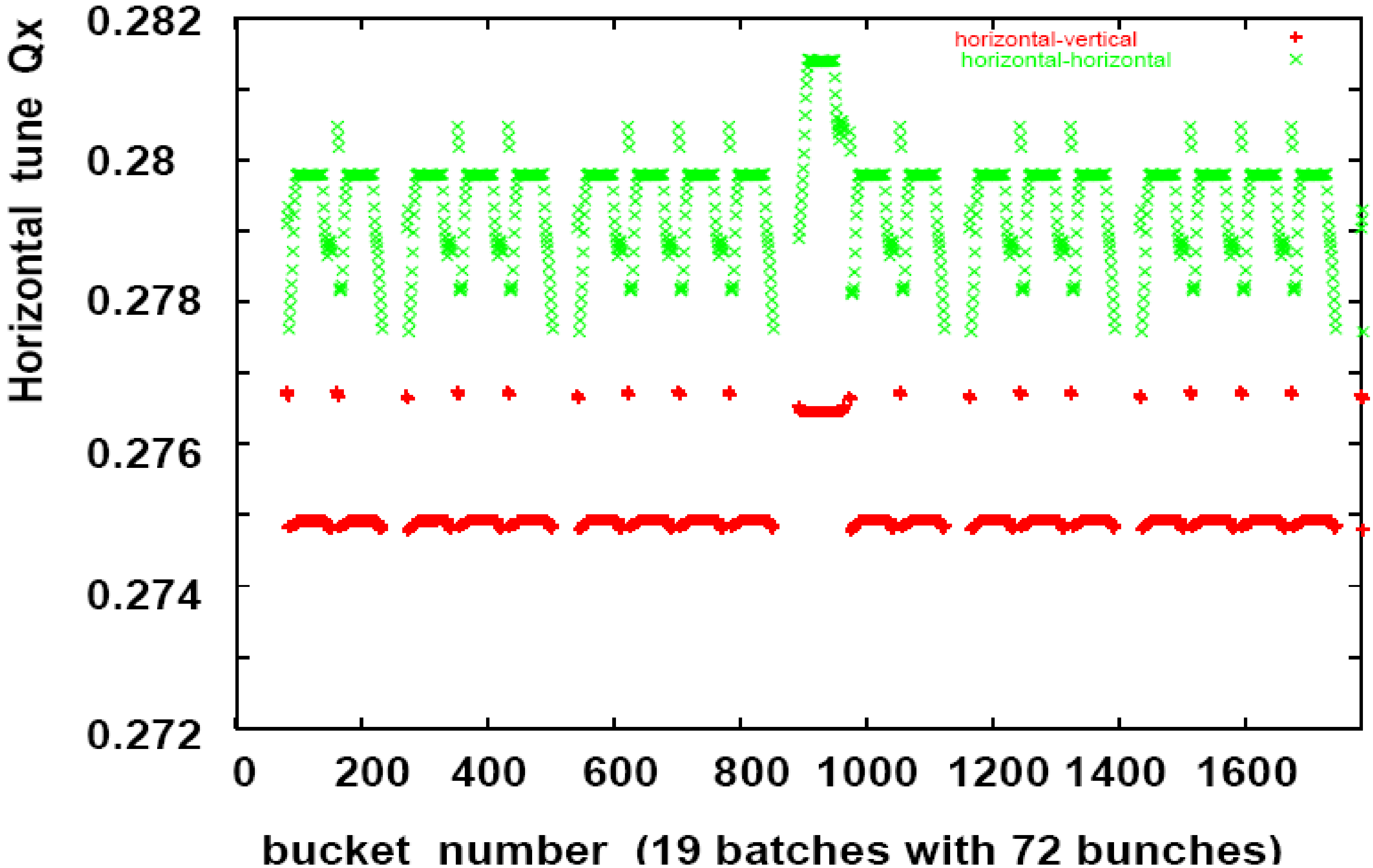
Plans

- Given the status of the codes and groups, budget guidance and available resources we, most probably, will be able to accomplish the task in FY09
- In FY08 we can:
  - Get LHC lattice and load it into all codes
  - Scan tunes around nominal
  - Scan chromaticity dependencies
  - Observe “bad” b-b-effects vs N_p
- We will work in close contact with BBLR team

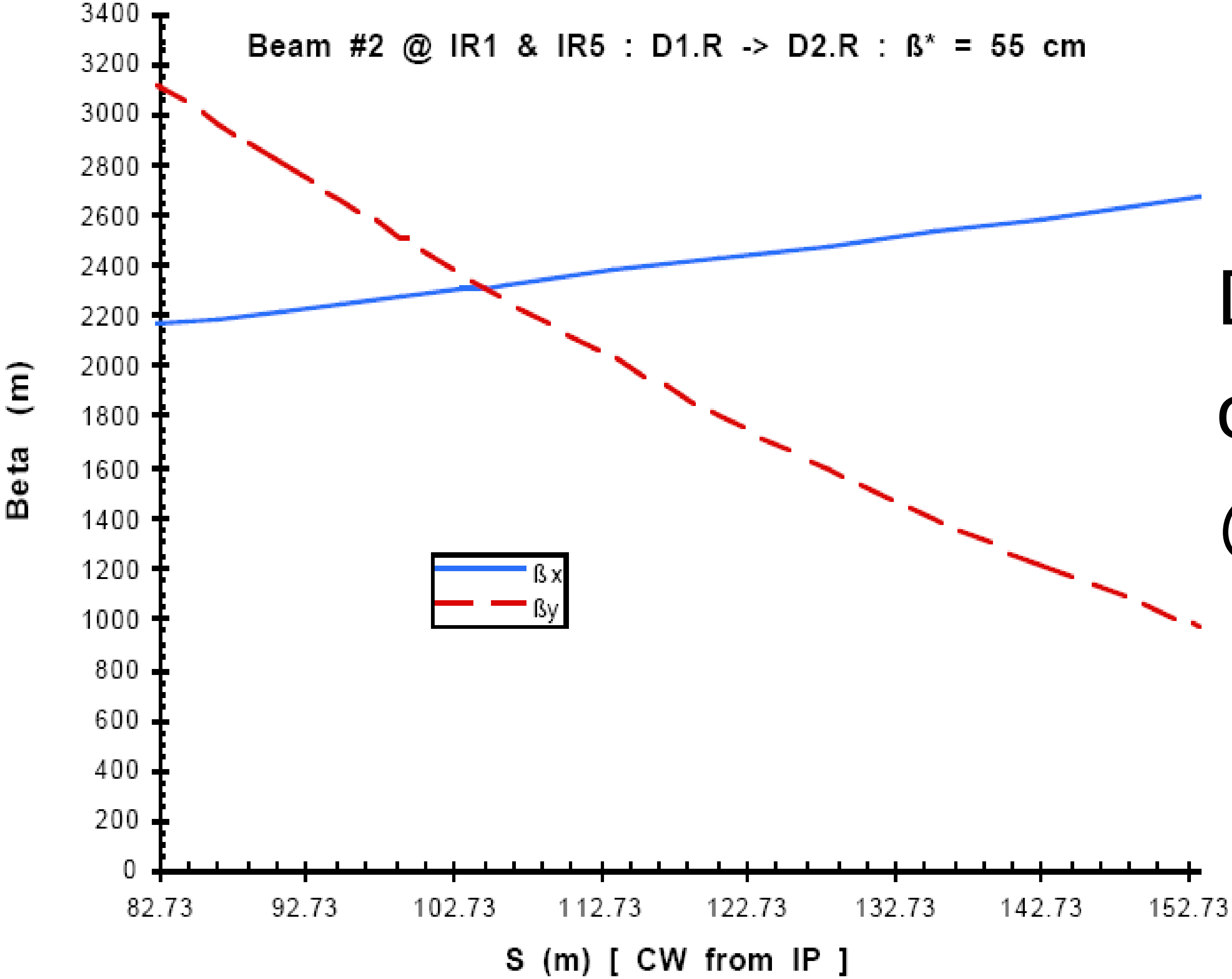
Long Range Compensation

- DC wire can do the job better
  - simpler
  - cheaper
  - … but only for reasonable beam-beam separations (3…4…5? Sigma)
- But (!) Electron Lens can
  - act as “electron wire” at ANY separation
  - not infinite current! (enough for 2-4 parasitics)
  - current variable bunch-by-bunch
  - can compensate b-b-b tune spread in *XX* crossing with many parasitics (next slide)

Bunch tunes for *XY* and *XX*



Location in LHC – I (55 cm)



J.Johnstone

LARP-doc-560

D_x < 9 cm

σ = 1.1 mm

@ β=2300m

Resources

- Fermilab:
  - V.Kamerdzhiev and full time Engineer, 10% VS
  - A.Valishev, Yu.Alexahin (part-time, theory & simulation support)
- Brookhaven:
  - Y.Luo and his group to simulate and develop
  - W.Fischer – management and operation support
- CERN:
  - Excellent work by U.Dorda, hope for T.Pieloni
  - Support/interest from FZ, JPK, OB